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HOW TO BE EFFICIENT - A SIMPLE INTRODUCTION TO 'OPTIMIZATION',(U)

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A SIMPLE INTRODUCTION TO "OPTIMIZATION"

by

Chin Fan

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By: Chin Fan

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HOW TO BE EFFICIENT -- A SIMPLE INTRODUCTION TO "OPTIMIZATION"

By Chin Fan

How does one design an aircraft which has a minimum weight yet satisfies safety and reliability requirements? How can an aircraft reach maximum range with a given take-off weight? Questions like this can be answered with the help of "optimization".

"optimization" is a new field in modern scientific technology. It has been only a few decades - particularly the last decade - since it is considered as a special branch of research in technology. Its progress can not be separated from technology advance, practical demand, and the progress and popularity of computer science.

The Crigination of the "Optimization" Idea

The idea of optimization has been with us for a long time. For an example, way back in ancient time people already had answered the question of what is the shape of a closed curve formed by a rope of constant length and has a maximum area? The answer is the shape of a circle has the largest area compared to any other shape. Its theoretical proof was not provided until the 18th century.

In 1696, John Bernorelli made public a letter. In which he asked mathematicians to pay attention to the so called brachistochrone problem. This well-known problem is to find the curve joining two points, along which a particle falling from rest under the influence of gravity travels from the higher point A to the lower point B in the least time.(Figure 1) An initial guess

is that the straight line between A and B is the answer, since it is the shortest distance between these two points; hence the least time. Actually this is not true. After careful study, it turned out that the curve for brachistos (shortest) time (chronos) is a cycloid. The reason is that although the path is longer than straight line, in most part the particle is traveling at a higher speed on a cycloid path. It was the analysis of the circle and brachistochrone that led to the foraml foundation of the calculus of variation. Calculus of variation is very important in solving optimization problems.

In Chinese history there is the story of horse race between the king of Chi and Lord Tien Gee. Once upon a time, the king of Chi wanted to have a race between his horses and Lord Tien's. The rules called for each of them to select one horse each from their three stables: super, medium, and regular. The stake is a thousand gold coins for each catagory. Since the horses of the King of Chi's were better than those of Lord Tien's in the corresponding groups, Sun Pin; Lord Tien's advisor, devised the following strategy: He sent regular horse to race against the King's super horse, the super one against the king's medium, and the medium one against the king's regular. Lord Tien came out a thousand gold coins ahead. This is a simple example of "optimization".

From the above mentioned example, we can understand the reason for original thinking and development of "optimization" idea. It should be Pointed out that it can experience fast progress only when society has practical need for it. During world war II,

due to the practical needs in production organization, distribution of materials, deployment of forces, anti-submarine warfare, etc., theories of planning and counter measure started to emerge. Radar technology was invented and applied during world war II, it was a giant technology advance when compared with method of locating aircrafts by listening to the sound of their engines. This advance increased the probability of intercepting enemy bombers to ten times higher than previous method. Utilizing "optimization" procedure, it was pushed to twenty times. This example illustrates the fact that the research and application of "optimization" has practical meaning. Particularly, in the last decade, the demand of precision, reliability, and high speed on automatic control systems and space navigation systems created a series of tasks for "optimization". At the same time, because the advance in computer science, these problems not only can be described theoretically in mathematical models but can be actually solved numerically. On the other hand, because the popularity of computer technology, people can use "optimization" technique to solve more practical problems and draw more attention.

"Optimum" means good. Good and bad are relative. By "optimization", we mean that we try to reach the best objective under a given set of conditions. In daily life, when we talk about good and bad, it is only a qualitative concept. How good is "good"? It has no clear-cut standard. Therefore when we study practical problems, it is not enough to speak of "good " or "bad". We must also set a quantitative standard. If we can set up a standard for measuring "good" or "bad" based on the requirement of practical problems and express all constraints in mathematical terms,

then we can convert a practical problem into a mathematical problem. This is the mathematical meaning of "optimization."

Selection of Better Method

Next, we will discuss an example. Suppose that we want to make a certain type of machine. Every machine need three different size of axes A, B, and C. The specifications are the following:

Type	Parts spec.(meter)	No. of parts per machine
A	2.9	1
B	2.1	1
C	1.5	1

These axes have to be cut from cylindrical rods. Each of the rods is 7.5m long. The question is: how many rods does one need to make 100 machines? This is a case where we want to cut down on waste. This problem can be solved through empirical method. For an example, take 50 steel rods and cut two type A and one type C from each rod. One can get 100 type A and 50 type C. then take another 25 steel rods and cut two type B and Two type C from each rod. We now have fifty type B and fifty type C. We still need fifty type B or 17 steel rods. For this method, we use ninty-two steel rods. Of course, this is a possible way. However, is this the most cost-effective way? we can not answer it. If not, can we use mathematics to find the most cost-effective way?

We tabulate the different cutting methods in the following:

cutting method No.	No. of 2.9m rods (A)	No. of 2.1m rods (B)	No. of 1.5m rods (C)	Left over material(meter)
1	2	0	1	0.1
2	1	2	0	0.3
3	1	0	3	0
4	0	2	2	0.2
5	0	3	0	1.1
6	1	1	1	0.9

From the table, we see that cutting methods 5 and 6 have more left-over materials and are not suitable. Method 1 and 3 have less left-over materials but can not make a complete set; there is no 2.1m rods available. Hence, we must consider methods 2 and 4 and their proper combinations. Now our problem is: Using methods 1, 2, 3, and 4, how many rods do we need to provide our 100 sets and the least number of original rods?

Let the number of rods for method 1 be X_1,

the number of rods for method 2 be X_2,

the number of rods for method 3 be X_3,

the number of rods for method 4 be X_4,

Then number of type $A = 2X_1 + X_2 + X_3$

$$B = 2X_2 + 2X_4$$

$$C = X_1 + 3X_3 + 2X_4$$

For one hundred complete sets, we can obtain the following equatines:

$$2X_1 + X_2 + X_3 = 100$$

$$2X_2 + 2X_4 = 100$$

$$X_1 + 3X_3 + 2X_4 = 100$$

$$X_i \geqslant 0, \quad i = 1, 2, 3, 4.$$

The total number of rods used are

$$f(X_1, X_2, X_3, X_4) = X_1 + X_2 + X_3 + X_4 \qquad (2)$$

Our question is that under the constraint of equation (1) find the least value for (2). (2) is called the target function and (1) is the constraint. X_1 are the variables. This is an "optimazation" problem. The solutions are:

$X_1 = 20$, $X_2 = 40$, $X_3 = 20$, $X_4 = 10$;

$X_1 = 10$, $X_2 = 50$, $X_3 = 30$, $X_4 = 0$, or ......

Therefore, a total of ninty original rods are required. This is the most cost-effective way of doing it.

Examining the above example, it is obvious that there is no unique solution even for such a simple problem. If we try to use empirical "trial and error" method, optimized solution will not be found. Even if we reach the right solution through trial and error, we can not determine if it is the optimum solution. Using mathematics, the optionum solution can be easily found.

There are many questions in engineering which can be handled by the "optimization" method. For an example, if we want to design a multi-stage rocket and require that it has the least amount of fuel consumption yet reach a pre-determined speed. Or, for a given weight, a logical distribution of weight among the different stages to reach the maximum range. Another example is : to design an aircraft with the minimum weight yet satisfies safety and reliability requirements. Other problems are (least time for) air interception, changing of space orbitals, etc. These problems of course are more complicated than the rod cutting problem. Using "trial and error" method, even a large amount of work were done, only a possible way can be found. If "optimization" is applied, the consideration of every possibility is based on a particular strategy to reach optimum but avoid attacking the problem blindly and can reach the goal speedily. When computer is used, it will track down the best method automatically.

Best Design

As science and technology progress , every branch of study and every field of technology offer a large number of optimization problems. There are many different types of problems. One can classify them into different branches according to their characteristics. From the stand point of engineering application, we can classify them into three catagories: first, problem of controlling process, i.e., optimum control problem. Second , selection of plan, i.e., optimum design. The third one is testing problem, i.e., optimum testing.

Here, we are going to introduce optimum design concept. When we are working on certain engineering project, we always wish to select a better plan for implementation. However if complicated systems are involved, designers may not reach their goal if conventional design technique is adopted. For an example, if we are to design an aircraft according to the conventional method ,the designer will select the initial design parameters based on experience to form tentative plan. Then he calculates various characteristics of this design and compare them with requirements. In general the first estimate will not satisfy the requirements. Certain parameters have to be changed to form the second design and the above mentioned process will be repeated. Several iterations have to be made until the requirements are satisfied. For the change of any design parameter, other parameters such as weight, propulsion, aerodynamics, etc. have to be estimated to calculate the characteristics of the aircraft which requires a great deal of work. Hence the number of iterations has to be limited. In general, only several parameters can be adjusted (such as propulsion, wing load, aspect ratio of

wing, angle of swing wing, etc.). At the same time, practical design work requires testings to verify the design. During the design stage, testings such as wind tunnel test are very costly and takes long time. Therefore, the number of tests has to be limited. The design which is done according to this process can only satisfy the requirement of "practical design" but not "optimum design".

Using electronic computer to calculate a large number of various parameters for various designs in a short time will facilitate the selection of a better design. This method is better than "trial and error" method which is based on a very small number of designs based on experience or arbitrary subjective consideration. We should point out, however, that even though computer is used, it may be that none of the designs calculated by the computer is optimized. Then can we device a method which will not calculate all the possible designs yet the optimized design can be found? The answer is yes. Optimization theory and practice; particularly non-linear programming; provides the basis for optimization through computer. As mentioned previously, we convert a practical problem into a mathematical problem of optimization and form a math model to establish a standard for good or bad. The calculated result of every design can be compared with the previous one. Based on a special devised standard, a large number of bad designs can be discarded and not all the parameters need to be calculated in order to find the optimum design. This is an optimization process. This process is called optimum design.

According to foreign reports, Boeing Company of the U. S. used an optimum program to optimize the capacity of a high speed

transport aircraft. The result is to increase the passanger capacity from one hundred and ninty-two to two hundred and fifty-three; an increase of thirty one percent.

Right now, the field of optimum design for structures are very active. For simple structure, optimum design can save materials about seven percent when compared with conventional design. For more complicated structure, the saving is about twenty percent in material and forty percent in weight. For an example, according to available literature, applying non-linear programming to the structure of the wing can reduce the weight by thirty-five percent. Optimum design of structure not only results in light weight structure but also results in the selection of logical structure shape. A structure usually consists of many parts. Different parts will have different impact on the structure as a whole. The malfunction of any one part will have different influence on the whole structure. Therefore the probability of failure of different parts can be assigned different values. Important parts should have low values and unimportant parts can have higher values. This is a more economic way when compared with the way where every part have the same strength. It also increase the safety factor.

As we can see, there are many merits in using computer for optimum design. It should also be pointed out that even though human design has its defects, it has certain merits too. Because human beings have long period of practical experience, he can make instant decision for modification during the design process which is something the computer is incapable of doing. The question then is this: can we combine the high speed of a computer

with the experience of human beings? Modern technology now makes this a possibility. Right now, computer can do drafting and display. A design blue print can be physically realized on a computer. "Light pen" can be used to make corrections on display (fig. 2). Consequently, during the computing process the designer can interrupt the computation, correct the input data and change the analysis process as the case may be. Human experience and computer speed are united together to make the optimum design a result of human-machine interaction. Unnessary calculation is eliminated and efficiency is increased. At the same time, more insight in analysis process is gained through this mutual interaction which result in more effective use of a certain special rules and not following them blindly. This process is known as computer-aided design(CAD) which is widely used in aerospace industry.

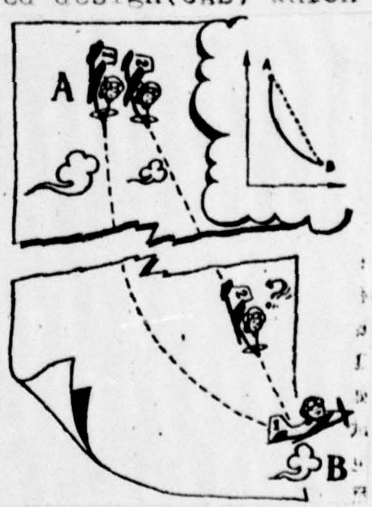
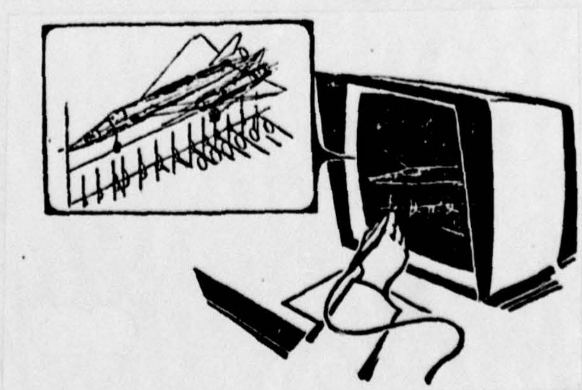


Figure 1 Brachistochrone

Figure 2 Using light pen to correct computer display



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